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Risk Perception and Risk Tolerance in Aircraft Pilots

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16. Abstract:

Poor pilot decision-making has been identified as a factor in a large percentage of fatal aviation accidents. Risk perception and risk tolerance are two factors that can significantly impact pilot decision-making. Inaccurate risk perception can lead pilots to ignore or misinterpret external cues that demand immediate and effective decisions to avoid hazards. High risk tolerance can lead pilots to choose courses of action that unnecessarily expose them to hazards and increased likelihood of accident.

Risk perception and risk tolerance are related and often confounded constructs. This study sought to separate these two constructs and to develop and evaluate measures that could be used to compare individual pilots on the constructs. A large sample of pilots visiting a government web site completed two risk perception, and three risk tolerance measures. They also completed a short scale assessing their involvement in hazardous aviation events and provided demographic information.

Analysis of the data showed that the five new measures demonstrated acceptable internal consistency. The measures of risk perception were only mildly related to risk tolerance, suggesting that these are separate constructs. As hypothesized, pilot perception of risk was negatively related to risk tolerance. In addition, risk perception demonstrated a small, but significant, correlation with self-reported involvement in hazardous aviation events. However, contrary to expectations, risk tolerance was not significantly related to hazardous events.

The results suggest that it is differences in cognitive skills required for accurate risk perception that place pilots are greater likelihood of accident involvement, rather than differences in underlying personality traits related to risk tolerance. The implications of the findings are discussed, along with limitations on the generalizability of the results, and suggestions for future research to improve the measurement scales are given.

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Risk Perception and Risk Tolerance in Aircraft Pilots

Risk is ubiquitous. There is no human state or action that is without risk, short of death itself, although there are clearly some states and actions that carry substantially more risk than others. Although flight in commercial aircraft is generally acknowledged to be the safest form of transportation, flying in general aviation (GA) aircraft is arguably toward the high end of the risk continuum, even though its practitioners (pilots) are generally oblivious to the magnitude of the risk (O'Hare, 1990).

Here, risk is being used in the commonly understood sense. That is, risk is the possibility of loss of life or injury, and it encompasses both the probability of an encounter with a hazard and the severity of a hazard. In that sense it is equivalent to what Sanders and McCormick (1993) term danger. Sanders and McCormick argue that the term risk should be used to denote the probability of an adverse encounter with a hazard, independent of the nature of the hazard. . However, the current usage follows Slovic, Fischhoff, and Lichtenstein (1980), who suggest that risk perception is determined by a combination of severity and likelihood of injury.

Risk assessment and management is one component of the broader process of pilot decision-making. Poor pilot decision-making has been implicated as a leading factor in fatal general aviation accidents (Jensen & Benel, 1977), and poor risk assessment can contribute significantly to poor decision-making. O'Hare (1990) suggested that "...an unrealistic assessment of the risks involved may be a factor in leading pilots to 'press on' into deteriorating weather." (p. 599) He developed an Aeronautical Risk Judgment Questionnaire to assess pilots' perceptions of the risks and hazards of general aviation. Hazard awareness was assessed by (a) having pilots estimate the percentage of accidents attributable to six broad categories, (b) ranking the phases of flight by hazard level, and (c) ranking detailed causes of fatal accidents (e.g., spatial disorientation, misuse of flaps). O'Hare found that pilots substantially underestimated the risk of GA flying relative to other activities, and similarly underestimated their likelihood of being in a GA accident. They were fairly accurate in their appraisal of the proportion of weather-related accidents, but estimated the rating for the pilot causal factors at 57%, when the actual figure is approximately 80%.

There are three major theories which attempt to explain behavior in the presence of risk. Risk homeostasis, as proposed by Wilde (Wilde, 1994; Trimpop & Wilde, 1994) maintains that people in any given activity have a target level of acceptable risk. People do not attempt to minimize risk, rather they seek to maintain an equilibrium by adjusting their behavior to maintain their target (non-zero) level. McKenna (1988) reviewed the evidence for and against risk homeostasis theory, "which argues that the level of risk people are willing to accept is the sole determining factor in overall accident involvement." (p. 469) He concludes that there is little evidence in favor of the theory.

Zero risk theory (Naatanen & Summala, 1974; Summala, 1988) was proposed in terms of driver behavior, and holds that driving and similar behavior is motivational in nature. The primary motive for using the traffic system is the mobility provided by the vehicle. According to zero risk theory, the perceived risk in a situation is the product of the perceived likelihood of a hazardous event and the importance attached by the individual to the consequences of the event (Ranney, 1994; Comsis Corp., 1995). According to this theory, as self-confidence increases (largely as a function of increasing experience in the situation), perceived risk diminishes to the point of zero perceived risk. That is, experienced drivers (and presumably, pilots) feel there is no real risk at all. It is interesting to note that Lester & Bombaci (1984) found that invulnerability was the preponderant response in a study of hazardous attitudes among pilots. Out of 5 alternative explanations for why they might engage in a risky aviation scenario, 43% of the pilots chose the response associated with an attitude of invulnerability, possibly indicating that they felt no risk from the situation.

The threat avoidance model (Fuller, 1988; 1984) is similar to the zero risk theory, in that it proposes that driving is motivational in nature. However, it suggests that drivers learn to anticipate hazardous events and avoid them, so that no negative consequences occur. Thus the driver rarely experiences any perceived risk of a crash, since those situations are avoided.

Assessment

In addition to the study noted earlier by O'Hare (1990) which examined pilot risk perceptions from the perspective of accident involvement, other researchers have proposed and evaluated measures of pilot risk-taking for selection purposes. A risk-taking exercise described by Imhoff and Levine (1981) has been used in several of these studies.

Shull and Dolgin (1988) investigated risk-taking as a predictor of success in US Navy aviation training. They administered the risk test described by Imhoff and Levine (1981) to a sample of 440 Navy flight students and tracked their performance in flight training. For a subgroup of 217 who had completed flight training, one of six correlations between pass/fail in training and risk test scores was significant ($r = -.184$), and suggested that increased risk taking was associated with success in training. As Shull, et al, point out, however, the result failed to replicate in the second and third trials of the risk test for the same group, so the finding is suspect.

In a later paper that seems to subsume their earlier sample, Shull and Dolgin (1989) report significant point-biserial correlations of .132 and -.184 between pass/fail for a sample of 322 student naval aviators and the risk task number right and reaction time, respectively, For 77 student naval flight officers, corresponding point biserial correlations of .277 and -.447 were obtained. Both these results indicate that the students who responded faster, as well as those who responded more often (that is, took more risks), were more likely to pass flight training

Siem, Carretta, and Mercatante (1988) used the Imhoff and Levine risk test in a study of U.S. Air Force pilot selection, but failed to find a significant correlation between scores taken from the test and pass/fail in undergraduate pilot training for a sample of 883 pilot trainees. Outside the area of pilot selection, Edkins, Coakes, and O'Hare (2000) compared objective with subjective perceptions of risk in commuter airline operations, and found that there was a strong tendency to rate external factors outside the control of the flight crew as more hazardous and more likely to occur than is indicated by the objective accident data. However, personal factors were rated as much less significant than is reflected in the accident data.

Williams (1999) gave a paper-and-pencil test assessing the willingness to fly toward an approaching storm under various conditions to 36 pilots. He found that the propensity was moderated by environmental aspects of the scenarios. He also found some indication that the pilots' aversion or propensity for risk were related to age and flight experience; younger or more experienced pilots were less risk averse. However, only 18 pilots were used in those analyses and the results were not statistically significant.

Training

Risk management is a central concept in much of the current aviation training. Although the terminology differs radically, the basic principles of risk management are incorporated in training designed for novice pilots (c.f., Kirkbride, Jensen, Chubb, & Hunter, 1996) to airline captains in the civilian sector, while similar programs, usually termed Operational Risk Management, have been established in each of the military services. All of these programs focus upon an assessment of risks through the identification of hazards and their expected likelihood, and the development of plans to counter those risk factors.

Regan, Triggs and Wallace (2000) described the development of a CD-ROM based training product for the development of risk perception skills in novice automobile drivers. This effort was in response to earlier studies that identified four specific skills as critical in moderating the crash risk of novice drivers. One of those skills was risk perception, which they define as "the ability to detect, perceive and assess the degree of risk associated with actual and emerging traffic hazards." (paragraph 1.1)

Risk Perception and Risk Tolerance

Risk perception and risk tolerance are related and often confounded constructs. Oppe (1988) discusses the concept of risk, and notes the difficulty of arriving at a good definition of risk perception and risk tolerance (termed risk acceptance by Oppe) because of the complexities of the situations in which these judgments are made. In particular, he suggests that risk tolerance may be very dependent upon the specifics of the situation and the transient utilities of a large number of factors.

DeJoy (1992) notes that the various risk perception formulations based on driver research suggest that "risk-taking behavior is mediated by the level of perceived risk in the outcome, suggesting that low levels of perceived risk would be associated with riskier driving." (p. 237) From his study of gender differences in risk perception by drivers, he concludes that, "The problem is not that young males do not consider driving to be a dangerous activity...The problem is that this danger is not perceived as applying to them personally." (p. 246) He suggests that interventions should be developed that personalize the risk to the driver, as opposed to making the risk an abstract statistical concept.

Brown & Groeger (1988) provide an insightful review and discussion of the relationship between risk perception and decision making, from the viewpoint of driver research. They note that, "Research ... demonstrates that acceptance and misperception of traffic risks present a relatively serious problem for road safety." (p. 585) They suggest a definition of risk which incorporates both the measure of the adverse consequences of an event (severity), and the likelihood of experiencing the event. They also point out that there are two elements to risk perception: information on potential hazards, and information of the joint abilities of the operator and the vehicle to prevent the potential of the hazard from being realized. They conclude, "Novice drivers...are insufficiently experienced to evaluate hazards adequately and inclined to asses their abilities inaccurately." (p. 592), and propose that driving experience leads to the development of schemata which represent the spatio-temporal characteristics of vehicles and traffic. The schemata are of central importance, because "...these are the internal representations by which risk is perceived and opportunities for risky manoeuvres declined or accepted." (p. 593)

Jonah (1986) notes that "risk-taking does not necessarily imply volition. Risks can be taken while driving with or without awareness of what one is doing." (p. 258) He concludes that, "The weight of the empirical evidence tends to support the view that young drivers may take risks more often because they are less likely to recognize risky situations when they develop." (p. 265)

Elander, West, and French (1993) provide an extensive review of research literature on individual differences and the relationship to driving accidents. With respect to hazard-perception ability, they concluded that "younger drivers rate potentially hazardous situations as less dangerous than do older drivers." (p 285). They also note, however, that there was "no evidence to date about whether the perceived level of hazardousness of situations is associated with crash frequency." (p. 285)

Risk perception is the recognition of the risk inherent in a situation. Risk perception may be mediated both by the characteristics of the situation and the characteristics of the viewer. Situations which present a high level of risk for one person may present only low risk for another. For example, the presence of clouds and low visibility may present a very high risk for a pilot qualified to fly only under visual meteorological conditions (VMC), but the same conditions would present very little risk for an experienced pilot qualified to fly in instrument meteorological conditions (IMC) in an appropriately equipped aircraft.

The viewer must therefore perceive accurately not only the external situation, but also their personal capacities. Underestimation of the external situation and overestimation of personal capacity leads to a misperception of the risk and is frequently seen as a factor in aircraft accidents. Risk perception may therefore be conceived as primarily a cognitive activity, involving the accurate appraisal of external and internal states.

By contrast, risk tolerance is better conceptualized as a personality trait. Risk tolerance may be defined as the amount of risk that an individual is willing to accept in the pursuit of some goal. Risk tolerance may be mediated both by the general tendency to risk aversion of the person and the personal value attached to the goal of a particular situation. Some goals may be judged as worthy of higher levels of risk exposure than other goals. For example, in one survey, pilots indicated that they would take more risks in order to return home for the Thanksgiving and Christmas holidays than they would for flying medicine to a remote village. (Driskill, Weissmuller, Quebe, Hand, & Hunter, 1998)

In an extensive review of research on young driver risk, Jonah (1986) found that "a major factor underlying this [automotive] accident risk – indeed perhaps *the* major factor – is risk-taking by youth." (p. 255, italics in original.)

Study Objectives and Hypotheses

The thesis of the present study is that both risk perception and risk tolerance may independently affect pilot decision making, and that an understanding of pilot actions requires a knowledge of both constructs as they exist in a particular pilot in a particular situation. The specific objectives of the present study were (a) to examine the relationship between risk perception and risk tolerance among pilots, and (b) to assess the degree to which these constructs were related to increased risk of an aviation accident.

To accomplish those objectives it was necessary to develop measures of both risk perception and risk tolerance. Previous studies have assessed pilots' estimates of global risk levels. For example, O'Hare (1990) asked pilots to estimate the percentages of accidents attributable to six broad causal categories (e.g., pilot, weather, etc.) and to rank causes of fatal accidents (e.g., spatial disorientation, misuse of flaps,

etc.) and found that pilots generally underestimate the level of risk of general aviation flight. He suggests that training that emphasized the relationship between personal actions and risk might be useful.

However, to be effective in reducing accidents, that training may need to be very specific in its focus. The automobile driver research shows that objective risk levels are not used in making tactical decisions (as opposed to strategic decisions, like choosing one form of transport over another). Therefore, for improving operator safety, whether a person can judge risk at the global level may be irrelevant. Once a person has committed to a mode of transport, it may not matter, from a practical point of view, whether they have a good appreciation of the global risk of that mode. It is much more important that they have a good appreciation for the elements (hazards) associated with that mode that contribute to the global risk. Having a good global risk assessment might alert the person to the need to be vigilant and conservative in their analyses of the environment, however zero risk theory (Naatanen and Summala, 1974) suggests that is not necessarily the case.

In contrast to measures of risk perception for broad categories of activities, for the current study, risk perception measures were created for realistic, specific aviation situations. It is believed that measures of risk perception for specific aviation situations would be more useful in predicting pilot behavior than global risk perceptions. There is a critical distinction between rating the risk of a specific situation and estimating the objective risk level of a general set of activities (for example, flying, riding a motorcycle, driving a car, etc.).

The present work attempts to clarify further some of the relationships among the factors present in the decision making process. It differs from previous studies of pilot risk perception with regard to the nature of the measurements. In addition, it separates the measurement of risk perception from the measurement of risk tolerance, which are often confounded. Specifically, this study seeks to:

1. Develop aviation-specific measures of risk perception and risk tolerance.
2. Assess the relationship between risk perception and risk tolerance.
3. Estimate the degree to which these constructs may relate to likelihood of accident involvement.

METHOD

Participants

Participants were recruited from visitors to an FAA sponsored Web site. Visitors to the site are required to create a personal identifier (call sign) to gain access to the site, and are encouraged, though not required, to provide an email address. The call sign can be any name of their choosing, and hence could not be used to identify any specific individual. In theory, the email address could be used to identify participants, however they were promised that the information would not be used in that way. Other than that potentially identifying information, the visitors and study participants remain anonymous. Participants who indicated they did not hold at least a student pilot certificate were excluded from the analyses.

An inducement to participate was used – inclusion in a series of drawings for aviation-related prizes. All participants who completed all the study exercises were entered into a drawing for one of three carbon monoxide detectors, and additional prizes were available to participants who obtained high scores on the risk tolerance exercises. In order to be eligible to receive one of the five prizes, the participant must have supplied an email address. The five winners were notified using the email address and asked for their mailing address. This was the only exception to the promise of anonymity as indicated above, and was clearly stated in the instructions provided to participants.

There are approximately 4,500 registered users of the Web site and approximately 2,400 visited the site during the period of the study. Of that number, 642 completed at least one of the study exercises, and slightly over 400 completed all the study requirements. Demographic characteristics of the participants are given in Tables 1 and 2. Characteristics of the initial sample (N = 642) who completed at least one exercise, and the final sample (N = 402) who completed all the study exercises are provided. The proportions of pilot certificate holders in the US pilot population are also included for comparison. The numbers of participants who completed each of the sequential exercises are given in Table 3.

Table 1. Sample Demographics for Continuous Variables.

	Initial Sample			Final Sample		
	N	M	SD	N	M	SD
TOTFLY[1]	667	1041.6	2641.5	411	839.3	1917.7
RECFLY[1]	664	84.6	117.8	409	82.6	109.1
XCFLY[1]	646	606.5	2137.4	408	464.7	1357.0
AGE[1]	654	45.3	12.4	411	45.4	12.4
YEAR[1]	654	1988	14	411	1989	13.4

Note 1: See Table 7 for variable definitions and abbreviations.

Table 2. Sample Demographics for Categorical Variables.

	Initial Sample	Final Sample
Certificate		
Student (STU)[2] (16.4%)[1]	16.1%	14.1%
Private (PPL)[2] (41.6%)[1]	57.7%	60.5%
Commercial (COM)[2] (20.0%)[1]	19.4%	21.2%
Airline Transport (ATP)[2] (22.1%)[1]	5.3%	4.1%
Instrument Rating (IFR)[2]		
Yes	39.1%	40.9%
No	60.9%	59.1%
CFI Rating (CFI)[2]		
Yes	9.8%	9.2%
No	90.2%	90.8%
Military Experience (MIL)[2]		
Yes	5.5%	5.3%
No	94.5%	94.7%
Type of Flying (ACT)[2]		
Receiving Instruction	22.2%	22.0%
Personal Pleasure	53.7%	57.4%
Personal Business	4.3%	3.4%
Part-time Flight Instructor	3.7%	3.4%
Full-time Flight Instructor	1.8%	2.2%
Air-taxi or Charter	0.4%	0.2%
Corporate	0.6%	0.7%
Agriculture Aerial Application	0.1%	0.2%
Military	1.0%	1.0%
Scheduled Commuter (Part 135)	0.0%	0.0%
Air Carrier (Part 121)	0.9%	0.7%
Other	7.7%	8.0%

Note 1: Proportion of these certificate holders in the total US pilot population (Source: FAA 1999 Annual Report on Aviation System Indicators).

Note 2: See Table 7 for variable definitions and abbreviations.

Table 3. Numbers of participants in each exercise.

Exercise	N
Risk Perception 1	642
Risk Perception 2	570
Risk Tolerance 1	441
Risk Tolerance 2	428
Risk Tolerance 3	411
Hazardous Events	402

Instrument Development

Only one previous measure (Imhoff & Levine, 1981) had been developed to address pilot risk tolerance. This study incorporates that measure, as well as two new measures for the assessment of risk tolerance. Additionally, because this study departs considerably from the previous research on risk perception and tolerance, it was necessary to develop new measures of risk perception.

Risk Perception. Two instruments were developed to assess pilots' perceptions of risk. Each instrument consisted of a series of brief scenario descriptions, depicting situations and activities with what was believed to be a broad span of risk. The two instruments differ with respect to the person involved in the risky scenario.

In the first exercise (Risk Perception 1) the scenarios were presented as if a third party were involved in the situation. (See Table 4 for the complete instrument.) There were 17 scenarios in the exercise.

In the second exercise (Risk Perception 2) the scenarios were presented and the participant was asked to rate the risk as if he or she were involved in that situation tomorrow. (See Table 5 for the complete instrument.). There were 26 scenarios in this exercise.

The specific scenarios presented in the two instruments were different, however some scenarios shared a common theme of adverse weather encounters. The scenarios were developed based upon information taken from accident reports, descriptions of events provided by participants in previous surveys of pilots, and the personal experiences of the author. Each set of scenarios was intended to represent a broad spectrum of conditions, ranging from benign to exceptionally hazardous. In addition to aviation scenarios, the second risk perception measure included some common activities (such as driving a car on the freeway, crossing a street, climbing a ladder) in order to provide reference points for possible cross-modal studies.

Each of the two exercises used a common rating scale to assign a risk rating to the scenarios. This rating scale ranged from 1 (low risk) to 100 (high risk), and anchor descriptions were given for the two extremes and for the mid-point (50).

Risk Tolerance Three instruments were developed to assess pilots' risk tolerance levels. Each of the three instruments structured the risk tolerance decisions in terms of aviation situations, so as to focus pilots' attention on assessments of aviation risk. One instrument dealt, ostensibly, with aviation maintenance issues, while the other instruments dealt with weather-related decisions.

Each participant entered the risk tolerance exercises with their own individual motivation for engaging in the exercises. Uncontrolled, some participants might be content simply to take the easiest, safest, alternative in each exercise; while others would strive to maximize their score, in order to demonstrate mastery of the situation or to fulfill some other need, unrelated to the aim of this study. I attempted to control for this extraneous effect by establishing a common level of motivation which would encourage those who would otherwise skip through the exercises to attempt the tasks, while at the same time restraining those participants who would take any risk, because it was just a game and they had nothing to lose.

In real aviation settings, in order to get where one wants to go, it is not possible to sit forever on the ground (taking zero risk) or to fly headlong through all obstacles on the most direct route (ignoring all risks). Rather, it is necessary to consider the risks in the context of the desired outcome, and to expose oneself to the minimum risk necessary to accomplish the goal. Clearly, the risks and rewards of actual flying cannot be duplicated in what amount to computer-based games. However, to parallel reality as closely as possible, some degree of risk must be present to both encourage and constrain behavior.

To provide a common level of motivation to engage in the risk tolerance exercises, participants were told that drawings would be held to award prizes to study participants. Pilots who had a combined score on the three risk tolerance exercises in the top 10% were entered in a drawing for a global positioning system (GPS) receiver – a very desirable item among pilots. Pilots who had a combined score in the top 25% were entered in a drawing for a transceiver – also a desirable aviation accessory, but only about one-third the cost of the GPS receiver. By limiting eligibility to those participants with the highest scores, they

Table 4. Risk Perception 1 Items Sorted by Mean Risk Rating.

Item	M	SD	Scenario
4	96.8	5.8	Low ceilings obscure the tops of the mountains, but the pilot thinks that he can see through the pass to clear sky on the other side of the mountain ridges. He starts up the wide valley that gradually gets narrower. As he approaches the pass he notices that he occasionally loses sight of the blue sky on the other side. He drops down closer to the road leading through the pass and presses on. As he goes through the pass, the ceiling continues to drop and he finds himself suddenly in the clouds. He holds his heading and altitude and hopes for the best.
3	89.4	10.5	A line of thunderstorms block the route of flight, but a pilot sees that there is a space of about 10 miles between two of the cells. He can see all the way to clear skies on the other side of the thunderstorm line, and there does not seem to be any precipitation along the route, although it does go under the extended anvil of one of the cells. As he tries to go between the storms, he suddenly encounters severe turbulence and the aircraft begins to be pelted with hail.
15	85.9	12.3	For the first part of this late night flight, the low-time VFR pilot has enjoyed a spectacular view of the stars as he cruised at 8,500 feet with over 25 miles visibility. As he nears his destination airport, which sits on the far side of a large lake, he notices that the visibility is decreasing because of haze nearer the surface. As he starts across the lake at about 2,500 feet he loses sight of the lights on the shore, and the dim lights scattered far apart on the ground seem to be indistinguishable from the stars.
2	85.1	14.2	The pilot is in a hurry to get going and does not carefully check his seat, seat belt, and shoulder harness. When he rotates, the seat moves backward on its tracks. As it slides backward, the pilot pulls back on the control yoke, sending the nose of the aircraft upward. As the airspeed begins to decay, he strains forward to push the yoke back to a neutral position.
1	79.6	17.6	On short final, a pilot drops his microphone on the floor. He looks down while bending over trying to reach it. He inadvertently moves the control yoke and the aircraft banks sharply.
14	79.3	14.3	An instrument-rated pilot on an IFR flight plan has just climbed through a 4000 foot thick layer of clouds. Although icing was not forecast, he notices a trace of ice on the edges of the windscreen. The aircraft is not equipped for flight into known or forecast icing conditions. As he approaches his destination airport, air traffic control issues a clearance that will require him to hold for approximately 15 minutes in the cloud layer.
6	74.9	16.3	During the planning for a 2 hour cross-country flight, a pilot makes a mistake in computing the fuel consumption. He believes that he will have over an hour of fuel remaining upon arrival, but he will really only have about 15 minutes of fuel left.
9	73.9	15.6	When he took off about an hour earlier, there was a quartering headwind of about 15 knots. He made it into the air, but it was a rocky takeoff, and one he hoped none of the other pilots at the small airport noticed. Now as he entered the downwind leg for landing, he noticed that the windsock was indicating almost a direct crosswind of about the same strength. On final he is holding a large crab to keep from drifting away from the centerline, and as he starts the flare he begins to drift toward the side of the runway.

(Continued)

Table 4 (Continued)

8	72.0	16.1	It is late afternoon and the VFR pilot is flying west into the setting sun. For the last hour, the visibility has been steadily decreasing, however his arrival airport remains VFR, with 4 miles visibility and haze. This is a busy uncontrolled airfield with a single East-West runway. He decides to do a straight-in approach.
7	69.4	17.7	After working a full day, a businesswoman drives out to the airport for her three hour flight home. She is tired, and the sun is setting, but the weather forecast is for clear sky and good visibility. About an hour after takeoff, she begins to feel very tired and sleepy. She regrets not bringing any coffee along, and opens the cockpit air vent to get some fresh, cool air.
5	68.2	20.2	Just after takeoff a pilot hears a banging noise on the passenger side of the aircraft. He looks over at the passenger seat and finds that he can't locate one end of the seatbelt. He trims the aircraft for level flight, releases the controls, and tries to open the door to retrieve the seatbelt.
17	66.1	16.8	While cruising at 4,500 feet AGL, the engine on the single-engine aircraft sputters and quits. The pilot checks the fuel settings and tries to restart the engine but is unsuccessful. He sees a level field within gliding distance and turns toward it. He will be landing into the wind.
11	58.0	21.0	The instructor pilot had been suffering from a cold and when he arose in the morning, he took an over-the-counter antihistamine to try and control his runny nose. After a morning of giving instruction in the flight simulator, he had a lesson scheduled after lunch with a pilot working on his COM certificate. He felt a little drowsy, but the weather was good and they were going to be working on short-field landings, so he did not cancel the lesson.
16	45.0	27.5	It is time for an oil change and the pilot/owner decides to do it himself. He consults with his local A&P mechanic and then follows his instructions. He does not have the work inspected afterwards and makes the appropriate log book notation himself.
10	32.1	22.3	While on a local sightseeing flight, the pilot notices that the weather is deteriorating to the west. A line of clouds is moving in his direction, but they are still over 20 miles away. He decides to cut his flight short and turns to return to his home airfield about 25 miles east of his present position.
13	27.1	21.2	An experienced pilot with a rated passenger are taxiing out for takeoff. They are at a controlled airfield, on the ground-control radio frequency. They have been cleared to "taxi to and hold short of Runway 31" and are now approaching the hold-short line.
12	25.4	20.7	A pilot is cruising in good weather to a destination airport about an hour away. It is midday, and there are three hours of fuel on board.

* Scale 1 (low) to 100 (high). Risk is for third party, low-time GA pilot (unless specified otherwise).

Table 5. Risk Perception 2 Items Sorted by Mean Risk Rating.

Item	M	SD	Scenario
18	76.3	17.3	Start a light aircraft with a dead battery by hand-propping it.
26	76.1	17.2	At night, fly from your local airport to another airport about 150 miles away, in a well-maintained aircraft, when the weather is marginal VFR (3 miles visibility and 2,000 foot overcast.
21	75.0	14.7	At night, take a cross-country flight in which you land with 30 minutes of fuel remaining.
19	73.4	18.3	Make a two-hour cross country flight with friends, without checking your weight and balance.
7	72.2	15.9	Fly in clear air at 6,500 feet between two thunderstorms about 25 miles apart.
22	68.5	16.9	Take a two-hour sightseeing flight over an area of wooded valleys and hills, at 1,000 above ground level.
14	68.0	17.4	During the daytime, fly from your local airport to another airport about 150 miles away, in a well-maintained aircraft, when the weather is marginal VFR (3 miles visibility and 2,000 foot overcast).
10	67.2	17.4	Make a traffic pattern so that you end up turning for final with about a 45 degree bank.
17	66.3	14.7	Drive your car on a freeway near your home, during the day, at 65 MPH in moderate traffic, during heavy rain.
4	65.6	19.2	Fly across a large lake or inlet at 500 feet above ground level.
9	62.4	18.2	During the daytime, take a cross-country flight in which you land with 30 minutes of fuel remaining.
2	55.5	23.4	Jaywalk (cross in the middle of the block) across a busy downtown street.
15	55.4	20.1	Fly across a large lake or inlet at 1,500 feel above ground level.
11	54.5	15.2	Drive your car on a freeway near your home at night, at 65 MPH in moderate traffic.
23	53.7	19.9	At night, fly from your local airport to another airport about 150 miles away, in clear weather, in a well-maintained aircraft.
5	52.9	21.4	At night, take a cross-country flight in which you land with over an hour of fuel remaining.
8	52.2	18.9	Take a two-hour sightseeing flight over an area of wooded valleys and hills, at 3,000 above ground level.
24	49.1	18.9	Fly across a large lake or inlet at 3,500 feet above ground level.
20	47.5	13.5	Drive your car on a freeway near your home during the day, at 65 MPH in moderate traffic.
16	45.6	20.5	Make a traffic pattern so that you end up turning for final with about a 30 degree bank.
3	39.9	21.4	Make a two-hour cross-country flight with friends, after checking your weight and balance.
13	38.8	20.1	During the daytime, take a cross-country flight in which you land with over an hour of fuel remaining.
1	35.8	21.8	During the daytime, fly from your local airport to another airport about 150 miles away, in clear weather, in a well-maintained aircraft.
6	33.9	22.0	Climb up a 10-foot ladder to replace an outside light bulb.
12	30.9	19.9	Take a two-hour flight in a jet aircraft on a major US air carrier.
25	17.7	16.8	Ride an elevator from the ground floor to the 25th floor of an office building.

Scale: 1(low) to 100 (high). Risk if you performed this tomorrow.

were encouraged to take some risks in order to gain points, while at the same time avoiding wildly reckless behavior which would cost them points.

In addition, simply as a reward for participation, all pilots who completed all the exercises were entered into a drawing for one of three carbon monoxide detectors – a useful safety accessory.

Risk Tolerance 1. The first risk tolerance exercise utilized the paradigm suggested by Imhoff and Levine (1981) for assessing risk-taking in pilots. There were 10 trials in this exercise. During each trial pilots were presented with a set of 10 aircraft, one of which is defective. Pilots were allowed to pick one aircraft for a flight, and, if they did not pick the defective aircraft, their score for that trial was increased. After each flight, the pilot chose another aircraft for the next flight. This process continued until either the pilot chose to end the trial, thus retaining the accumulated points, or they chose the defective aircraft, in which case they lost all the points accumulated for that trial. Points, if any, accumulated in each trial were added to the cumulative total. The objective, from the pilots' perspective, was to maximize the cumulative total by flying as many flights in each trial as possible.

Participants were told that the assignment of the defective aircraft was random. However, in order to control for exposure to success and failure, the actual determination of the defective aircraft was not random, but was fixed. To the participants it seemed that one particular aircraft out of the ten depicted was defective. However, in actuality which particular aircraft they chose was irrelevant. Rather, the defective aircraft was presented solely based upon the number of flights taken by a pilot in any particular trial. Specifically, for the 1st, 9th, and 10th trials, the pilot was not given a defective aircraft until the 10th flight of those trials. However, for the 2nd trial the pilot received a defective aircraft on the 2nd flight of that trial, regardless of which of the 9 remaining aircraft they chose. For the other trials, the defective aircraft was presented between the 4th and 8th flights. This procedure ensured that each pilot was equally free to express their risk-taking proclivity on the trials, without being prematurely terminated by a random encounter with a defective aircraft.

Risk Tolerance 2. A scenario involving a thunderstorm was used in the second risk tolerance exercise. In this exercise, pilots were presented with a scenario involving a series of flights (each constituting a separate trial) between two airports. However, two thunderstorms blocked the most direct route between the two airports, forcing a diversion around the storms. A gap of varying width between the storms was presented on each trial, and pilots could choose to either fly through the gap, or to divert around the storms. Because the score for this exercise was based on minimizing the distance flown, pilots had an incentive to fly between the two storms, whenever they thought they could do so. The pilots were instructed that if they choose to fly between the two storms, they might encounter severe turbulence, in which case their score would be penalized. They were also advised that the probability of an encounter with severe turbulence increased as a function of their proximity to the storms. Severe turbulence was (supposedly) random, but was more likely if the gap between the storms was small. Participants were given access to a government publication which recommended a separation of 25 miles from thunderstorms.

As in the first risk tolerance exercise, the incidence of turbulence was not, in fact, random, but was set to occur on the first five trials, but not thereafter. As in the first exercise, the purpose of setting (arbitrarily) the turbulence to occur on those five trails was to control exposure to the hazard, while not limiting the potential for expression of the participants' proclivity to risk taking on the other trials. These first five trials corresponded to gap sizes of 5 to 25 miles. There were 20 trials in this exercise.

Risk Tolerance 3. The third risk tolerance exercise was similar to the second exercise. However, in this exercise low clouds obscuring a mountain pass were used as the seemingly random hazard. As before the pilots were presented with 20 trials involving flights between two airports. A weather briefing was provided that indicated a deterioration of conditions, occurring with varying rapidity. In some instances the weather was forecast to deteriorate before the pilot could fly through the pass (80 minutes after departure), while in other cases the time to deteriorate was either equal to or greater than 80 minutes. The pilots were advised that, as when dealing with real weather, the forecasts may not be accurate, and conditions may change more rapidly or more slowly than predicted. Pilots were motivated to take the most direct route through the mountains to maximize their scores. However, they could elect to take the longer route around the mountains with a much lower risk of losing all the points for the trial.

Proxy Measure for Accident Involvement

Although flying in general aviation is a relatively risky activity (O'Hare, 1990), accidents are still infrequent events. Using accident occurrence as a criterion for the evaluation of new scales, therefore, presents some difficulties. Even in a relatively large (by psychological

research standards) sample, the number of pilots who have been in an accident is small. In the current sample, of the approximately 400 pilots with complete data, only 4% reported having been in an aircraft accident. This restricted distribution leads to severe restrictions on the maximum point-biserial correlation that may be observed. (Nunnaly, 1967, pg 133) In the present case, the maximum possible point-biserial correlation would be approximately .40.

To address this problem, Hunter (1995) developed a set of questions which assessed the numbers of times that a pilot had been involved in potentially hazardous events. The advantage of assessing the frequency of these hazardous events lies in the fact that they occur much more frequently than do accidents. In most instances, a hazardous event does not lead to an accident or incident. It is only in the rare occasions when a hazardous event occurs in combination with other factors or hazardous events that an accident ensues. The hazardous event scale was developed based on the simple premise that being in a hazardous event increases the likelihood of an accident, and that the more frequently a person is placed at increased risk by being in an hazardous event the more likely it is that an accident will eventually occur. Certainly the relationship is not completely deterministic, but in the absence of a better criterion the measurement of hazardous events is suggested as a proxy for accidents, the criterion of ultimate interest.

O'Hare and Chalmers (1999) administered 12 questions from this scale to a nationwide sample of pilots in New Zealand and obtained results that were very close to those reported by Hunter (1995) for pilots in the United States.

In the present study, ten questions from the original scale were used. One question asked whether the pilot had been in an aircraft accident, while the remaining nine questions measured involvement in various hazardous aviation events during the preceding 24 months. The questions are given in Table 6. A summary score (HAZ) was formed by summing the responses to all ten items.

Procedure

Pilots who visited the Web site were invited to participate in the study through a notice posted on the home page of the site. This notice directed potential participants to a page on which the aims of the research, the rules for participation in the prize drawings, and the usual human research subject assurances were displayed.

All exercises were completed in the same order. Following a brief review of the demographic data provided when they originally registered with the Web site, participants were asked for some additional demographic information. They then completed the two risk perception exercises, the three risk tolerance

Table 6. Questions Comprising the Hazardous Events Scale.

Item Number	Question[1]
1	How many aircraft accidents have you been in (as a flight crew member)?
2	How many times have you run so low on fuel that you were seriously concerned about making it to an airport before you ran out?
3	How many times have you made a precautionary or forced landing at an airport other than your original destination?
4	How many times have you made a precautionary or forced landing away from an airport?
5	How many times have you inadvertently stalled an aircraft?
6	How many times have you become so disoriented that you had to land or call ATC for assistance in determining your location?
7	How many times have you had a mechanical failure which jeopardized the safety of your flight?
8	How many times have you had an engine quit because of fuel starvation, either because you ran out of fuel or because of an improper pump or fuel tank selection?
9	How many times have you flown into areas of instrument meteorological conditions, when you were not on an instrument flight plan?
10	How many times have you turned back or diverted to another airport because of bad weather while on a VFR flight?

Note 1: All questions referred to events during the last 24 months.

exercises, a scale which assessed their encounters with hazardous aviation events, and an aviation attitude scale (which will not be addressed in this paper).

Participants were free to complete all the exercises at one time, or to complete any portion they wished, and then come back at a later time to complete the remainder.

The study was activated on February 1 and data collection ceased on May 8, 2001.

RESULTS

The exercises were administered in a fixed order, and the numbers of participants who completed each succeeding exercise declined steadily as participants withdrew from the study for unspecified reasons. Indeed, some participants (N = 34) did not even complete the first exercise after having registered. To best use the available data, each analysis used the maximum number of participants for whom appropriate data were available. For example, the reliability analysis of Risk Perception 1 used 621 participants for whom complete item response data were available. This differs from the 642 participants who completed this exercise, because some of their item responses were missing (i.e., blank) and reliability analysis requires complete item responses for all items. However, later analyses of Risk Perception 1 and Hazardous Events used a much smaller number of participants because, of the 642 participants who completed Risk Perception 1, only 402 also completed Hazardous Events.

Using this approach means that the numbers of participants reported in each of the analyses will differ. However, to restrict the analyses only to those participants for whom complete data are available on all measures would needlessly and arbitrarily discard useful information. It is recognized that the constantly shifting sample sizes may contribute to some confusion; however, the value of the added data is worth the cost.

To help the reader follow the analyses, the major variables used in the analyses and the abbreviations that will be used to conserve space and improve legibility in the tables are listed in Table 7. Except for the computation of coefficient alpha, SPSS™ (Version 9.0) was used for all statistical computations.

Risk Perception 1 (Third-party Risk)

Reliability. A coefficient alpha was computed using the STATISTICA™ reliability procedure. For a sample of 621, the obtained internal consistency equals .845. The average inter-item correlation was .258.

Item and Scale Scores. The means and standard deviations for each of the 17 items are given in Table 3. An overall composite risk rating score (P1MEAN) was computed for each individual by taking the mean of the 17 item ratings. A baseline risk rating score (P1BASE) for each individual was computed by taking the mean of items 10 and 12 (see Table 3 for item content). I chose those two items because inspection of the scenarios for these items suggested that they describe normal general aviation activities without any particular elements that would elevate risk. This score, therefore, represents the individual's baseline evaluation of risk in nominal general aviation activities. Similarly, a weather risk rating score (P1WX) was computed for each individual by taking the mean of items 3, 4, 14, and 15. These items all deal with various aspects of weather. Therefore, this score represents the individual's evaluation of risk in weather-related GA activities. Table 8 contains the means and standard deviations for these composite scores.

Risk Perception 2 (Personal Risk)

Reliability. A coefficient alpha was computed using the STATISTICA™ reliability procedure. For a sample of 514, the obtained internal consistency equals .937. The average inter-item correlation was .376.

Item and Scale Scores. The means and standard deviations for each of the 26 items are given in Table 4. An overall composite risk rating score (P2FLY) was computed for each individual by taking the mean of the 20 items dealing with aviation. A composite risk rating score (P2LIFE) was computed by taking the mean of the 6 items which dealt with non-aviation scenarios (e.g., driving a car, crossing a street, etc.). A baseline risk rating score (P2BASE) was computed for each individual by taking the mean of items 1, 13, and 23 (see Table 4 for item content). The scenarios for these three items describe normal general aviation activities without any particular elements that would elevate risk. This score, therefore, represents the individual's baseline evaluation of risk in nominal general aviation activities. Similarly, a weather risk rating score (P2WX) was computed for each individual by taking the mean of items 7, 14, and 26. These items all deal with various aspects of weather. Therefore, this score represents the individual's evaluation of risk in weather-related GA activities. Table 8 contains the means and standard deviations for these composite scores.

Risk Tolerance 1 (Broken Airplane)

Reliability. A coefficient alpha was computed using the STATISTICA™ reliability procedure. For a

Table 7. Variable Definitions and Abbreviations.

Full Name	Abbreviation
P1MEAN (Mean of all 17 items)	P1MEAN
P1BASE (Mean of items 10, 12)	P1BASE
P1WX (Mean of items 3, 4, 14, 15)	P1WX
P2FLY (Mean of 20 aviation items)	P2FLY
P2LIFE (Mean of 6 non-aviation items)	P2LIFE
P2BASE (Mean of items 1, 13, 23)	P2BASE
P2WX (Mean of items 7, 14, 26)	P2WX
Tolerance 1 Summary (Mean of items 9 and 10)	T1SUM
Tolerance 2 Set 1	T2_SET1
Tolerance 2 Set 2	T2_SET2
Tolerance 2 Summary (Mean of Set1 and Set2)	T2SUM
Tolerance 3 Summary (Total Weighted Proportions)	T3SUM
Hazardous Events (for previous 24 months) – Sum of All Items	HAZ
Pilot Certificate – STU	STU
Pilot Certificate – PPL	PPL
Pilot Certificate - COM	COM
Pilot Certificate – ATP	ATP
Instrument Rating (Coded 0=No, 1=Yes)	IFR
Certified Flight Instructor (Coded 0=No, 1=Yes)	CFI
Military Flying Experience (Coded 0=No, 1=Yes)	MIL
Main Type of Flying Activity (See Table 2 for list)	MAINFLY
Total Flying Time in Career	TOTFLY
Recent Flying Time (during last 12 months)	RECFLY
Cross country flight time	XCFLY
Age in Years	AGE

Table 8 Means and Standard Deviations of Computed Variables.

		M	SD	N
Risk Perception 1				
	P1MEAN	66.5	9.9	643
	P1BASE	28.8	19.3	643
	P1WX	87.9	7.5	643
Risk Perception 2				
	P2FLY	57.9	12.7	524
	P2LIFE	45.2	12.2	553
	P2BASE	41.7	18.8	600
	P2WX	71.4	14.8	589

sample of 377, the obtained internal consistency equals .913. The average inter-item correlation was .539. These coefficients are based upon only those participants who responded to all 10 items in this scale. Excluding those participants who did not complete all the items yields the most conservative estimate of the internal consistency.

Item and Scale Scores. The means and standard deviations for each of the 10 trials are given in Table 9. An overall composite risk rating score (T1SUM) was computed for each individual by taking the mean of trials 9 and 10. On these two trials the subject did not encounter a defective aircraft until the 10th flight of the trials. Therefore, these two trials offer an opportunity to observe the participants' level of risk tolerance, with the least constraints placed upon their potential responses. The first trial is also interesting in this regard, since it allows for observation of the risk tolerance of the subject before they encounter any of the contrived disasters of the subsequent trials. The mean of the composite score (T1SUM) was 4.84, with a standard deviation of 1.37 (N=409).

Risk Tolerance 2 (Thunder Storm Avoidance)

Reliability. A coefficient alpha was computed using the STATISTICA™ reliability procedure. For a sample of 364, the obtained internal consistency equals .864. The average inter-item correlation was .273.

Item and Scale Scores. This exercise consists of two approximately equivalent sets of 10 trials each. For each set of trials (1-10 and 11-20) the trial with the lowest storm separation chosen by each subject was identified. These are identified as "T2_SET1" and "T2_SET2". The frequency distribution for these two variables are given in Table 10. The correlation between T2_SET1 and T2_SET2 equals .520 (N=421; $p < .01$), which might be interpreted as a measure of parallel forms reliability. Remember, however that these two sets differ in that during the first set the participant is exposed to five trials in which turbulence is present. Further, there is undoubtedly some learning effects that occur during those trials, which are not present during the second set. Therefore, the correlation of .520 may more reasonably be taken as a lower bound of their relationship.

Risk Tolerance 3 (Mountain Weather)

Reliability. A coefficient alpha was computed using the STATISTICA™ reliability procedure. For a sample of 375, the obtained internal consistency equals .901. The average inter-item correlation was .308.

Item and Scale Scores. Four scores were computed which represent the numbers of times the pilot selected Route A (through the mountains) for each of the predicted times for weather passage. The computed variables are:

1. Variable T3T60 — Instances with predicted time < 80 minutes
2. Variable T3T80 — Instances with predicted time = 80 minutes
3. Variable T3T100 — Instances with predicted time = 100 minutes
4. Variable T3T120 — Instances with predicted time = 120 minutes

Table 9. Risk Tolerance 1 (Broken Airplane) Mean Scores for Each Trial.

Trial	Limit[1]	M	SD
1	10	5.3	1.7
2	2	2.0	0.4
3	8	5.2	1.5
4	3	3.0	0.5
5	6	4.9	1.3
6	8	5.0	1.4
7	4	3.8	0.6
8	5	4.4	0.9
9	10	4.8	1.4
10	10	4.9	1.5

Note 1: If this number of flights within the trial is reached, the subject loses the accumulated points for that trial.

Table 10. Frequency Distribution of Tolerance 2 Scores (N=426).

	Set 1	Set 2
5 miles	22.5%	5.4%
10 miles	13.4%	4.7%
15 miles	10.8%	8.7%
20 miles	14.3%	18.7%
25 miles	8.7%	20.1%
30 miles	8.2%	18.4%
40 miles	12.0%	16.1%
50 miles	4.0%	3.5%
75 miles	1.2%	1.2%
100 miles	.2%	.5%
Over 100	4.7%	2.6%

Note: First 5 trials (5-25 miles) in Set 1 result in crash on Route A.

Each of these numbers was then converted into a proportion, by dividing by the number of opportunities the pilot had to fly under each of the specified predicted times. An overall score (T3SUM) was computed by summing the four proportions, using an a priori weighting scheme of:

$$\text{T3SUM} = 4 \times (\text{T3T60}) + 3 \times (\text{T3T80}) + 2 \times (\text{T3T100}) + 1 \times (\text{T3T120}).$$

Thus, higher scores would indicate riskier decisions by the pilot. The means and standard deviations of these variables are given in Table 11.

Relationships Among the Risk Perception, Risk Tolerance, and Demographic Variables

Intercorrelations of risk perception and risk tolerance measures and the continuous (or binary) demographic variables are given in Table 12. One-way ANOVAs were conducted to examine effects of pilot certificate level on scores, with post hoc comparisons of means using the Bonferroni technique.

Results of the ANOVAs are given in Table 13. Overall significant differences among the pilot certificate levels (e.g., Private, Commercial, Airline Transport) were found only for the measures from Risk Perception 2. Results of the post hoc comparisons for the Risk Perception 2 measures are given in Table 14.

Hazardous Events and the Perception and Tolerance Measures

Frequency counts for the 10 hazardous event items are given in Table 15. Correlations between the total hazardous event scores (HAZ) and the risk perception and risk tolerance measures are given as the last row in Table 12. Significant correlations with the hazard scores were found for the scores from Risk Perception 2. The negative correlations indicate that those pilots who rated the weather scenarios as low in risk experienced larger numbers of hazardous events than those pilots who rated the weather scenarios as high in risk. None of the risk tolerance measures correlated significantly with the hazard criteria, and generally had values close to zero.

Table 11. Descriptive Statistics for Risk Tolerance 3 – Mountain Weather Scores.

	N	M	SD
T3T60	413	.8668	1.2264
T3T80	412	1.8398	1.8766
T3T100	411	3.2847	1.9252
T3T120	411	2.2871	1.0956
T3SUM	411	17.8297	12.4270

DISCUSSION

Evaluating the Measures

As the first step in the evaluation of pilot risk perception and risk tolerance, it was necessary to create measures of those constructs, targeted at specific, concrete aviation situations. The five instruments developed for that purpose exhibit acceptable psychometric properties in terms of internal consistency.

The two risk perception instruments exhibit moderate correlations of .501, and .445 between the corresponding baseline and weather scores, respectively. This suggests that they are measuring somewhat the same constructs. Remember, however that the risk perceptions addressed by the two instruments are oriented differently. Perception 1 is oriented towards risk experienced by others, while Perception 2 is oriented towards personal risk. It may be, as suggested by these results, that these are distinct constructs. As no other instruments have been developed which assess risk perception in quite this manner, it was not possible to obtain external construct validation.

The three risk tolerance instruments also exhibited good internal consistency. However, examination of their intercorrelations suggests that they may not be functioning as intended. Even though the two instruments that assessed risk tolerance regarding weather (Tolerance 2 and Tolerance 3) were very similar in their design and the types of decisions required of the participants, the correlation between the summary scores was only moderate (-.485). Further, both of these instruments had low correlations (approximately 0.2) with Risk Tolerance 1 – the only instrument that had been used in previous studies of risk-taking by pilots.

From Table 12 it is apparent that many of the risk perception measures are significantly correlated with pilot demographic characteristics, although the magnitude of those correlations are small. The preponderance of negative values clearly shows that higher levels of experience and qualification are associated with lower levels of risk perception. This might be interpreted as support for the zero risk theory (Summala, 1988; Naatanen et al., 1974) which suggests that higher levels of experience lead to lower levels of perceived risk. It is also interesting to note that perceived personal risk (from Perception 2) shows

Table 12. Correlations of Demographic, Perception, and Tolerance measures, and Hazard Score. (N varies from approximately 400 to 550).

	AGE	IFR	TOTFLY	RECFLY	XCFLY	MIL	CFI
AGE	1.000	.127*	.150*	-.025	.108*	.039	.017
IFR	.127*	1.000	.374*	.387*	.305*	.194*	.367*
TOTFLY	.150*	.374*	1.000	.428*	.938*	.436*	.289*
RECFLY	-.025	.387*	.428*	1.000	.309*	.176*	.468*
XCFLY	.108*	.305*	.938*	.309*	1.000	.390*	.146*
MIL	.039	.194*	.436*	.176*	.390*	1.000	.052
CFI	.017	.367*	.289*	.468*	.146*	.052	1.000
P1MEAN	-.081*	-.036	-.093*	.045	-.124*	-.035	.039
P1BASE	-.106*	-.061	-.129*	.007	-.119*	-.038	-.037
P1WX	.040	-.090*	-.117*	-.068	-.149*	-.045	.029
P2FLY	-.102*	-.202*	-.244*	-.179*	-.237*	-.080	-.133*
P2LIFE	-.025	-.030	-.010	-.044	-.027	.020	.032
P2BASE	-.090*	-.177*	-.221*	-.178*	-.200*	-.076	-.155*
P2WX	-.025	-.268*	-.303*	-.309*	-.293*	-.094*	-.148*
T1SUM	.021	.039	-.052	-.056	-.068	.025	-.021
T2SUM	.024	-.024	-.094	-.071	-.077	-.053	.019
T3SUM	-.118*	-.002	-.004	-.004	-.012	-.003	-.061
HAZ	.198*	.253*	.368*	.315*	.297*	.093	.189*

	P1MEAN	P1BASE	P1WX	P2FLY	P2LIFE	P2BASE	P2WX	T1SUM	T2SUM	T3SUM
AGE	-.081*	-.106*	.040	-.102*	-.025	-.090*	-.025	.021	.024	-.118*
IFR	-.036	-.061	-.090*	-.202*	-.030	-.177*	-.268*	.039	-.024	-.002
TOTFLY	-.093*	-.129*	-.117*	-.244*	-.010	-.221*	-.303*	-.052	-.094	-.004
RECFLY	.045	.007	-.068	-.179*	-.044	-.178*	-.309*	-.056	-.071	-.004
XCFLY	-.124*	-.119*	-.149*	-.237*	-.027	-.200*	-.293*	-.068	-.077	-.012
MIL	-.035	-.038	-.045	-.080	.020	-.076	-.094*	.025	-.053	-.003
CFI	.039	-.037	.029	-.133*	.032	-.155*	-.148*	-.021	.019	-.061
P1MEAN	1.000	.589*	.615*	.568*	.460*	.443*	.444*	-.092	.258*	-.169*
P1BASE	.589*	1.000	.077*	.458*	.251*	.501*	.246*	-.035	.207*	-.156*
P1WX	.615*	.077*	1.000	.365*	.322*	.177*	.445*	-.065	.189*	-.125*
P2FLY	.568*	.458*	.365*	1.000	.560*	.864*	.775*	-.109*	.221*	-.137*
P2LIFE	.460*	.251*	.322*	.560*	1.000	.436*	.451*	-.060	.100*	-.097
P2BASE	.443*	.501*	.177*	.864*	.436*	1.000	.557*	-.133*	.205*	-.139*
P2WX	.444*	.246*	.445*	.775*	.451*	.557*	1.000	-.029	.204*	-.147*
T1SUM	-.092	-.035	-.065	-.109*	-.060	-.133*	-.029	1.000	-.198*	.215*
T2SUM	.258*	.207*	.189*	.221*	.100*	.205*	.204*	-.198*	1.000	-.485*
T3SUM	-.169*	-.156*	-.125*	-.137*	-.097	-.139*	-.147*	.215*	-.485*	1.000
HAZ	-.049	-.049	-.061	-.125*	.067	-.112*	-.203*	-.039	-.021	-.039

* Correlation is significant at the 0.05 level (2-tailed).

Table 13. ANOVA of Perception and Tolerance Measures by Pilot Certificate Level.

		SS	df	MS	F	Sig.
P1MEAN	Between	223.300	3	74.433	.766	.514
	Within	61348.352	631	97.224		
	Total	61571.652	634			
P1BASE	Between	2788.209	3	929.403	2.507	.058
	Within	233951.234	631	370.763		
	Total	236739.443	634			
P1WX	Between	558.801	3	186.267	3.273	.021
	Within	35907.937	631	56.906		
	Total	36466.738	634			
P2FLY	Between	4707.214	3	1569.071	10.184	.000
	Within	79499.313	516	154.068		
	Total	84206.527	519			
P2LIFE	Between	960.136	3	320.045	2.162	.092
	Within	80688.183	545	148.052		
	Total	81648.319	548			
P2BASE	Between	13091.939	3	4363.980	13.130	.000
	Within	196424.239	591	332.359		
	Total	209516.178	594			
P2WX	Between	11891.747	3	3963.916	19.775	.000
	Within	116262.048	580	200.452		
	Total	128153.795	583			
T1SUM	Between	1.637	3	.546	.285	.836
	Within	769.274	402	1.914		
	Total	770.911	405			
T2SUM	Between	38.405	3	12.802	2.753	.042
	Within	1957.940	421	4.651		
	Total	1996.345	424			
T3SUM	Between	56.471	3	18.824	3.246	.022
	Within	2342.998	404	5.799		
	Total	2399.469	407			
HAZ	Between	492.995	3	164.332	14.698	.000
	Within	4326.959	387	11.181		
	Total	4819.954	390			

*Note: Application of Bonferroni technique would result in failure to reject null hypothesis for comparisons where significance >.005.

Table 14. Summary of Post-hoc Mean Comparisons for Pilot Certificate Levels.

		Mean Difference (Row – Column)			
		STU	PPL	COM	ATP
P2FLY					
	STU			6.85	11.33
	PPL			5.63	10.12
P2BASE					
	STU			10.62	20.20
	PPL			7.08	16.65
P2WX					
	STU			7.50	18.10
	PPL			7.41	18.02
	COM	-7.50	-7.41		10.60

Note: Bonferroni technique applied. All differences shown significant, $p < .05$

Table 15. Frequency Counts of the Hazardous Event Items.

	Number of Reported Events						
	0	1	2	3	4	5	6+
Accident	96%	4%	0%	0%	0%	0%	0%
Low fuel	81%	17%	2%	0%	0%	0%	0%
On-airport precautionary landing	60%	22%	9%	4%	5%	0%	0%
Off-airport landing	96%	3%	0%	1%	1%	0%	0%
Inadvertent stall	93%	5%	1%	0%	1%	0%	0%
Lost	91%	8%	1%	0%	0%	0%	0%
Mechanical failure	70%	20%	7%	2%	1%	0%	0%
Engine quit due to fuel	96%	3%	0%	1%	0%	0%	0%
Flown VFR into IMC	82%	14%	2%	1%	1%	0%	0%
Turn back or divert for weather	43%	24%	17%	4%	12%	0%	0%

consistently higher correlations with the demographic variables than does the perceived risk for others (Perception 1).

Also from Table 12, it is evident that the risk tolerance measures generally had almost no relationship to pilot demographic variables. Except for the correlation between age and Risk Tolerance 3, none of the other correlations were significant, and were generally close to zero.

The Relationship of Risk Perception to Risk Ttolerance

One question of interest was whether pilots who rate weather hazards as being relatively lower in risk also tend to get higher weather risk scores—that is, do they tolerate more weather risks? To address this question, I examined the correlations of the weather risk perception measures with the weather risk tolerance scores. From Table 12, the correlations of P1WX (weather risk perception) with T2SUM and T3SUM (weather risk tolerance measures) are 0.189 and -0.125, respectively. Both of these correlations are statistically significant ($p<.05$). High scores on both Perception 1 and Perception 2 indicate perception of weather scenarios as higher in risk. High scores on Tolerance 1 and Tolerance 3 indicate that the subject is more risk tolerant – that is, takes higher risks. However, the scoring system is reversed for Tolerance 2, such that low scores indicate higher risk tolerance.

Therefore, the correlation of 0.189 between P1WX and T2SUM indicates that high risk perception was associated with lower risk tolerance. Pilots who perceived the weather scenarios as higher risk tended to have a lower tolerance for the weather risk decisions. Because high scores on Tolerance 3 indicate high levels of risk taken, the negative correlation of –0.125 between P1WX and T3SUM means that pilots who rated the weather scenarios as high in risk, tended to make less risky decisions on the tolerance exercise. Thus the two correlations lead to a consistent interpretation.

Similar results were obtained when comparing Perception 2 with the tolerance scores. The correlation of P2WX with weather tolerance measures were 0.204 and -0.147, for T2SUM and T3SUM, respectively. Both these correlations are also statistically significant ($p<.05$). Results from all the correlations thus demonstrate that pilots who rate weather as risky tend to be less tolerant of weather risk.

A similar but considerably more modest result is obtained when the more general measure of risk-taking (Tolerance 1) is compared with the risk perception measures. Although all the correlations between the Tolerance 1 measure (T1SUM) and the risk perception measures are negative, consistent with the previous results, only two of the six correlations are significant, and all are considerably smaller than those obtained for the other risk tolerance measures.

Relationships to Hazardous Activities

To assess the degree to which the measures from these instruments might be associated with accident involvement, they were correlated with an index of involvement in hazardous activities. As shown in Table 12, significant correlations were obtained between measures computed from Perception 2 and the hazardous activity score. Specifically, correlations of -0.125, –0.112, and –0.203 were obtained for the overall aviation (P2FLY), baseline (P2BASE), and weather (P2WX) risk perception scores, respectively. The negative correlations indicate that higher levels of perceived risk for the scenarios were associated with lower numbers of hazardous events. Note that in Table 12 there is a correlation of 0.560 between the general non-aviation risk level (P2LIFE) and the level of risk perception for flying (P2FLY). If general risk perception, as measured by the items dealing with non-aviation scenarios (P2LIFE), is held constant, then partial correlations of –0.202, -0.169, and –0.263 between the hazardous activity score and P2FLY, P2BASE, and P2WX, respectively, are obtained. However, Table 12 also shows that there were significant correlations between the risk perception measures and pilot demographic variables – specifically, recent and total flight time. If these two variables are also held constant, then considerably attenuated partial correlations of -.0923, -.0762, and -.1158 between the hazardous activity score and P2FLY, P2BASE, and P2WX, respectively are obtained. Only the correlation for P2WX remains statistically significant ($p < .05$; $N = 345$) when these other effects are included.

None of the correlations between the risk tolerance measures and the hazardous events index were statistically significant, and all were close to zero.

Study Limitations and Threats to Generalizability

There are several aspects of this study which may limit the generalizability of the results. Primarily, these aspects are related to the sample of participants and the data collection methodology.

First, recall that this sample was obtained from pilots who had, for unspecified reasons, visited a Web site that provides self-evaluation exercises and training aimed at general aviation pilots. They are, therefore, self-selected from a pool of pilots who (1) had Internet access and, (2) knew about and chose to visit this Web site during the period of the data collection.

The demographic information presented in Table 2 clearly indicates that this sample differed from the population of U.S. pilots in terms of pilot certificate. The results certainly should not be taken as representing pilots holding airline transport certificates, since they are clearly underrepresented in this sample.

Second, the demographic data and reports of involvement in hazardous events are based upon self-report, and are therefore subject to inaccuracies due to respondent forgetfulness, bias, or misinterpretation of the questions. Because the data collection was anonymous, external validation of the participants' responses was not possible. The questions dealing with involvement in hazardous events are probably the most susceptible to these errors.

Third, to simplify both the programming burden and the instructions to the participants, the order of administration of the data collection was fixed, not random. This means that performance on the later tasks may have been affected by exposure to the earlier tasks. Because of the attrition from the study noted earlier, this also means that the participants who completed the later tasks are a subset, with potentially different characteristics, of those who began the study. Examination of the characteristics of the initial and final samples given in Tables 1 and 2 suggest that this did not substantially change the composition of the sample, however it is possible that some other factor (for example, gender) not assessed in the study, was related to the decision to withdraw before completion of all the tasks.

Fourth, the attempt to establish a significant motivating force in the risk tolerance tasks may not have been equally effective with all pilots. Recall that in these tasks pilots are motivated to obtain a high score in order to be entered into a drawing for two highly desirable aviation accessories. Without a motivation, participants have no reason to attempt to maximize their scores by engaging in higher risk activities in the exercises. However, some pilots reported that they were indifferent to the prizes, and simply completed the tasks for altruistic or other personal reasons. Lack of a strong motivator may have led those pilots to limit their choices in the exercises to the low risk alternatives, while in a motivated state they might have chosen high risk alternatives. This effect would tend to attenuate the obtained results.

Fifth, the synthetic risk tolerance tasks may not be indicative of behavior in the real world. Clearly, the risks inherent in flight are not present in these computer-based exercises. Rather, it is assumed, as it is in much of psychological research, that the personal attributes which moderate risk tolerance in the laboratory also act in approximately the same way to moderate risk tolerance elsewhere.

Sixth, the data collection medium may have influenced the outcomes. Using the Web as a psychological laboratory has advantages and disadvantages too numerous to discuss here, and readers are directed to Birnbaum (2000) and Dillman (2000) for further information. However, as a new activity, much needs to be done to work out how to perform many tasks that are easy in the university laboratory, but difficult when the experimental cubicle is in someone's home a thousand miles away. Questions of subject recruitment and attrition, and generalizability of the results will remain for some time. It is important to note that this and similar studies are not statistical probability surveys. Rather, they are identical in most respects to the usual psychology experiment conducted with a sample of convenience. It might be argued that drawing a more-or-less random sample from a national population results in a more representative sample and, hence, more generalizable results than are obtained from students in the freshman psychology class or a small group of experts chosen solely because they were the only participants available. However, the data to address that argument are not available here.

CONCLUSIONS

In this study, new measures were developed to assess pilot risk perception and risk tolerance. The data from those measures demonstrated that, for weather, pilot perception of risk is negatively related to tolerance for risk. This finding is important because it means that pilots who do not perceive the risks associated with adverse weather are more likely to engage in higher risk activities when dealing with weather.

The measures of risk tolerance were only mildly related to the measures of risk perception, suggesting that these are quite distinct constructs. Interestingly, none of the measures of risk tolerance were related to involvement in hazardous aviation activities. Measures of risk perception, however, were related to hazardous event activities – pilots with a low perception of risk tended to be involved in more hazardous events. This seems to agree with the finding that pilots with low risk perception are more tolerant of risks. However it must be noted that although statistically significant, the effect size obtained for the relationship between risk perception (specifically, perception of weather risks) and hazardous events is very small, accounting for around 4% (from Table 12) of the variance. Additional work would certainly be required to improve the reliability and validity of these scales before they could be used, even as a simple self-awareness exercise for pilots.

Consistent with the zero risk theory (Naatanen and Summala, 1974), higher levels of experience and qualifications were associated with lower levels of perceived risk, except for student pilots who tended to have a low estimation of the risks in aviation. Apparently they have not learned enough to estimate these risks.

It is clear that additional research is needed beyond this first, exploratory study. In particular, the measures of risk tolerance need to be refined. It may be that the weak intercorrelations among these measures and the present failure to find significant relationships between those measures and hazardous activities can be attributed to poor measurement of that construct. A next step might be to attempt to measure the construct in a more realistic setting, possibly in a flight simulator.

Additional efforts are also needed to explore the construct validity of these measures. Assessments of their relationships with constructs such as locus of control and adventure-seeking would be worthwhile. An assessment of the relationship of gender to performance on the perception and tolerance measures would also be interesting.

The results of the present study suggest that it is risk misperception, not high risk tolerance, that is associated with exposure to hazardous aviation events. This conclusion is in agreement with previous research (O'Hare and Smitheram, 1995; Goh and Wiegmann, 2001) that shows that pilots who continue flight into adverse weather conditions have a poor perception of the risks. If the hazardous events index is a reasonable and valid proxy for actual accident involvement, then this suggests that risk misperception may place these pilots at increased risk of accident involvement. However, the link to accidents must remain a tentative conclusion until the specific relationship between the proxy measure and actual accident involvement is established empirically.

Although it is somewhat surprising to find that risk tolerance was unrelated to the hazardous event criterion, from the perspective of a regulatory agency charged with improving aviation safety, these are actually very encouraging results. It is far better to have a problem caused by pilot skill deficiencies than to have a problem caused by pilot personality traits, because the former are far easier to change than the latter. Deficiencies in pilot skill may be addressed through a variety of training interventions, and the mechanisms for developing and delivering these interventions are well established and understood. Further, pilots are generally receptive to initiatives aimed at improving their skill levels. Thus, although this is by no means a trivial undertaking, changes in pilot perception may be accomplished with a reasonable expectation of success. On the other hand, making fundamental changes to the levels of risk that pilots are willing to tolerate would be a considerable challenge. If, as is proposed here, risk tolerance reflects a basic personality trait of the individual, then it would be exceptionally difficult to substantially change that trait within any reasonable and acceptable intervention program. Fortunately, the data indicate that the aviation community is not faced with that challenge.

Changing risk perception is not a straightforward undertaking, however, since the factors that influence risk perception are complex and confounded. It is probably not appropriate simply to raise everyone's perception of risk. Rather, risk perceptions must be made more valid. The results of this study show that experience changes risk perception. More experience leads to lower perceptions of risk. Since higher levels of experience are generally considered better, in the sense that pilots with more experience are more competent, then it may well be that their assessments are correct. Since they are more competent, then the scenarios presented to them represented truly lower levels of risk. However, more work is needed to identify those factors that result in inaccurate perception of risk. In that regard, there are three broad avenues of approach. First, researchers may investigate how pilots arrive at their assessment of their personal levels of competency and what causes those assessments to be inaccurate. Second, they may investigate how pilots gather information from the environment and identify the cues associated with conditions of high risk. Third, they may investigate the interaction between the pilots perception of self and their perception of the world and the resulting decision – "Yes, I can do this," or "No, I cannot do this."

Research by Wiggins and his associates (Wiggins and O'Hare, 1993; Wiggins, O'Hare, and Lods, 2000) suggests that pilots can be trained to look for and recognize the weather cues indicative of increased weather risk. In addition, O'Hare at the University of Otago and Wiegmann at the University of Illinois are conducting research on problem framing and other factors that may influence continuation error – continuing flight into adverse weather conditions. Additional research is also needed to assess how environmental cues are combined to form the global risk perception for a situation. Better, and more specific measures of risk perception are also needed. Research into the mental processes by which perceptions of external risk and perceptions of internal capability, presumably in two different metrics, are combined to arrive at the go/no-go decision would also be very illuminating.

The present effort, and the suggested follow-on research, serve two purposes. First, they advance our scientific understanding of the processes and attributes of people and situations that contribute to decision-making, and potentially to accidents. Second, their results shape the interventions that will reduce accidents. The present results show that attempts to change risk tolerance (a potentially massive undertaking) would be far less effective in reducing accidents than training pilots in risk recognition skills. This supports the current approaches to training hazard identification and control and suggests that these programs need to be broadened and strengthened. It also shows that interventions aimed at changing risk tolerance would likely be ineffective, thus avoiding expenditure of resources in an area unlikely to reduce accidents. Risk may be ubiquitous, but with effective, research-based intervention programs, accidents may be prevented by improved pilot education regarding risk identification and management.

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